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IGNITION AND COMBUSTION OF COAL PARTICLES

By

C. O. Gomez and F. J. Vastola
Department of Materials Science and Engineering
The Pennsylvania State University, University Park, Pennsylvania 16802

INTRODUCTION

A fundamental understanding of the coal combustion process is important not only in the operation of combustion furnaces but also in the design of equipment for efficient burning, especially now when one of the requirements in the recent emphasis on coal utilization is clean burning. Even when the combustion of coal and char particles has been studied for a long time and extensive literature exists in the subject (1-4), this fundamental understanding has not been established. A clear demonstration is the wide variety of assumptions made in the most recent attempts of modeling the phenomenon (5-10).

The combustion of coal particles is a heterogeneous phenomenon involving a relatively unknown material and occurring in two stages: ignition and burn-out. Ignition depends on a balance between the rates of heat gain and loss to the particle; consequently the particle size, the environmental conditions, and the reactor geometry that defines the fluid dynamics of the system play important roles. The study of this complex phenomenon is difficult, because in addition to its transient character, it involves the simultaneous occurrence of a number of transport processes which apply to a system whose dimensions and characteristics change with time.

Two ignition mechanisms for coal particles are accepted. Their occurrence depends on the relative rates of two phenomena: the heating of the particle surface and the rate of volatile release. When the rate of heating of the particle surface is larger than the rate of volatiles release, the ignition takes place on the particle surface and the mechanism is called heterogeneous. In this case, the particle surface reaches a temperature high enough for reacting and igniting prior to extensive pyrolysis. On the other hand, when the rate of volatile release is larger than the rate of heating of the particle surface, the ignition occurs in the gas phase surrounding the particle and the mechanism is called homogeneous. In this case, the pyrolysis is so rapid that the particle surface is isolated from the external gaseous mixture by a volatile layer. To investigate the conditions which control the mode of ignition we conducted experiments utilizing single particles of coal.

EXPERIMENTAL

A schematic diagram of the apparatus is in Figure 1. The oxygen-nitrogen mixture is heated in the gas preheater and then sweeps the reaction zone where a single coal particle is introduced by gravity, using a specially designed injector. A light beam at location 1 is used to detect the time of the particles entry into the reaction zone. The gaseous products are rapidly cooled and split to be simultaneously measured by two nondispersive infrared analyzers, one for carbon monoxide and one for carbon dioxide. A photo transitor connected to a light pipe placed within the reaction zone is used to detect combustion generated luminosity. A microcomputer-based data acquisition system records the time of injection, the light generated by the particle's ignition and burnout, as well as the carbon monoxide and carbon dioxide concentration in the product gas stream.

In addition to the time of entry of the coal particle into the reaction zone the time of transit of the product gases from the reaction zone to the detector must be determined. This transit time was measured by injecting a short pulse of carbon dioxide into the reaction zone under the same conditions as used in an ignition run and measuring the time to detector response. To characterize any deformation of the product pulse as it flows from the reaction zone to the detector a similar short pulse of carbon dioxide was directly injected into the detector cell. The shape of the pulse after its travel through the system was compared with that resulting from the injection of the pulse directly into the detector cell. No appreciable difference was detected, indicating that the conditions used are very effective in reducing the deformation of the gas release curves.

A subbituminous coal (PSOC 648), whose characteristics are shown in Table I, was used in this study. Particles from the 850-1000 micron sieve fraction were injected into a reaction furnace swept with air at five temperature levels of 928, 980, 1076, 1118 and 1273°K.

TABLE I

CHARACTERISTICS OF COAL PSOC 648

Apparent Rank: *Subbituminous B*

Reflectance Rank: HVC

Proximate Analysis (as received)

Moisture	22.10%
Ash	4.58%
Volatile Matter	33.78%
Fixed Carbon	39.59%

Ultimate Analysis

	As Received	Dry Basis
Moisture	22.10%	%
Ash	4.58%	5.88%
C	53.01%	68.05%
H	4.00%	5.13%
S (total)	0.33%	0.42%
N	0.80%	1.03%
O (by difference)	15.18%	19.49%

RESULTS AND DISCUSSION

Typical results of the gas evolution during combustion are shown in Figure 2 for selected runs at the different temperatures used in this study. The carbon monoxide and carbon dioxide concentrations are plotted against time with zero time being that time when product gases are first detected. Homogeneous ignition, as evidenced by a peak in the carbon dioxide product curve, is detected at temperatures of 1076°K and higher. The integration of the gas evolution curves will give the total mass of carbon in the original particle, if all the carbon is oxidized to carbon monoxide or carbon dioxide, which means in the case of the combustion of a coal particle, the complete burn-out of the volatiles released in the early stages of the combustion. Experimental results suggest that this was the case, because the most difficult hydrocarbon to be oxidized--methane--detected during the pyrolysis of coal particles, was not found during their combustion.

The occurrence of either of the two mechanisms of ignition previously described can be easily determined from the results of the light intensity measurements presented in Figure 3. When a coal particle ignites homogeneously, the combustion in the gaseous phase of the volatile matter released from the particle produces an initial flash of light, followed by the glowing of the remaining particle as the heterogeneous combustion proceeds. On the other hand, when the ignition mechanism is heterogeneous, the initial flash of light is not observed and only the final glowing is detected.

The ignition mechanisms detected by light intensity and by gas release curves have been summarized in Table II. There is complete agreement between the two techniques, except at the intermediate temperature of 1076°K. This discrepancy however, is consequence of an insufficient amount of volatiles released by the particle for burning with enough intensity to generate a flash of light, when the gas temperature is 1076°K. However, the amount released is enough to be detected before the ignition begins on the surface of the particle. This is a clear advantage of the experimental approach used in this work and shows how both techniques complement each other.

The total combustion time can also be determined from light intensity measurements and from gas evolution curves. A comparison between the results given by the two techniques is presented in Figure 4, where the combustion time measured by carbon dioxide evolution is plotted against the value obtained from light intensity for coal particles. Carbon dioxide was selected over carbon monoxide because of the greater sensitivity of the carbon dioxide detector, which allows the measurement of the combustion time more accurately. The combustion times tend to be larger when they are measured by gas evolution than by light intensity. This tendency is not unexpected because light can be detected only after the particle temperature increases to a point at which it is visible from the background. This high temperature is reached after a period in which gases were already evolving.

An unexpected result is the decrease in the proportion of carbon monoxide in the product gases, as the gas temperature increases. If the measured concentrations of carbon monoxide and carbon dioxide are the results of the chemical reaction on the surface, an increase in the proportion of carbon monoxide is expected as the temperature rises. The opposite trend is a consequence of the gas phase oxidation of carbon monoxide to carbon dioxide, which modifies the relation of the primary products of the reaction. In any case, the occurrence of this gas phase reaction does not affect the results previously discussed, because they are based on the total carbon consumed in the particle, and the gas phase reaction only affects the relative distribution of carbon as carbon monoxide or carbon dioxide, but not the total carbon coming from the particle as the result of the chemical reaction.

TABLE II

MECHANISMS OF IGNITION DETECTED BY DIFFERENT TECHNIQUES IN THE COMBUSTION OF COAL PARTICLES

Gas Temperature (°K)	Run	Ignition Mechanism Detected by Light Intensity	Gas Evolution
928	150	Het	Het
	151	Het	Het
	152	Het	Het
	153	Het	Het
	154	Het	Het
980	115	Hom	Hom
	116	Het	Het
	117	Het	Het
	118	Het	Het
	119	Het	Het
1076	133	Hom	Hom
	134	Hom	Hom
	135	Het	Hom
	136	Het	Hom
	137	Het	Hom
1118	097	Hom	Hom
	099	Hom	Hom
	100	Hom	Hom
	101	Hom	Hom
	102	Hom	Hom
1283	081	Hom	Hom
	082	Hom	Hom
	083	Hom	Hom
	084	Hom	Hom
	085	Hom	Hom

CONCLUSIONS

A differential approach has been developed for the study of the combustion process of single coal particles. The experimental technique, based in the simultaneous measure of the carbon monoxide, carbon dioxide, and intensity of the light generated during the combustion, gives quantitative information about the ignition and the subsequent burn-off of the residual particle. The apparatus designed provides the special characteristics required in this study and the transition between the two ignition mechanisms is achieved within the range of operation conditions, for the coal used in this study.

The ignition mechanism is determined not only from measurements of light intensity during the combustion, a technique commonly used in the past, but also from the gas evolution curves which allow the quantification of the whole combustion process. The results show the convenience of using both as complementary techniques in the determination of the ignition mechanism.

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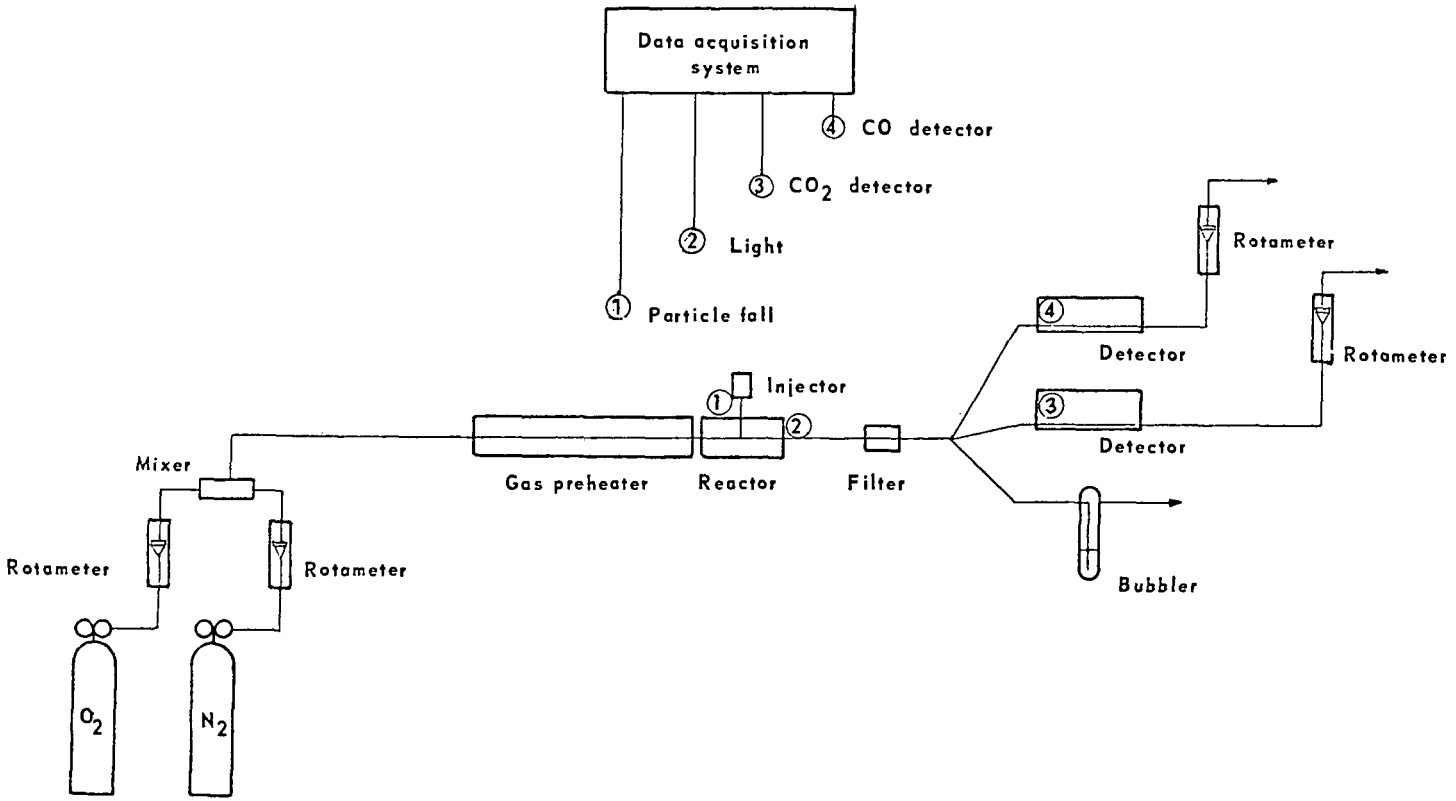

FIGURE 1. SCHEMATIC DIAGRAM OF THE APPARATUS

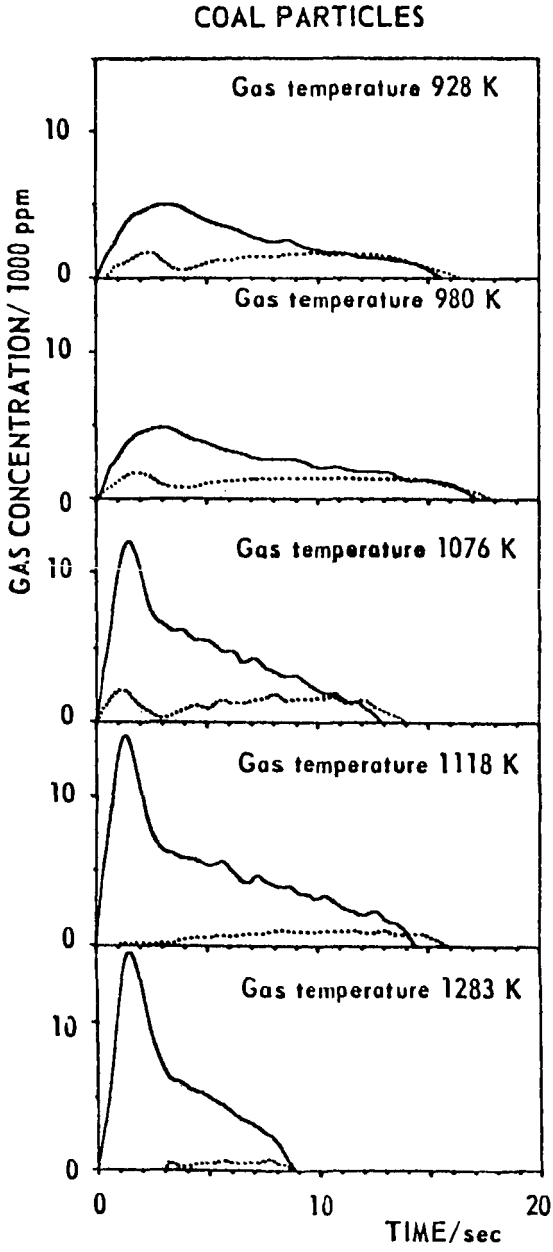

FIGURE 2. TYPICAL GAS EVOLUTION CURVES

(Continuous line CO_2 – Dotted line CO)

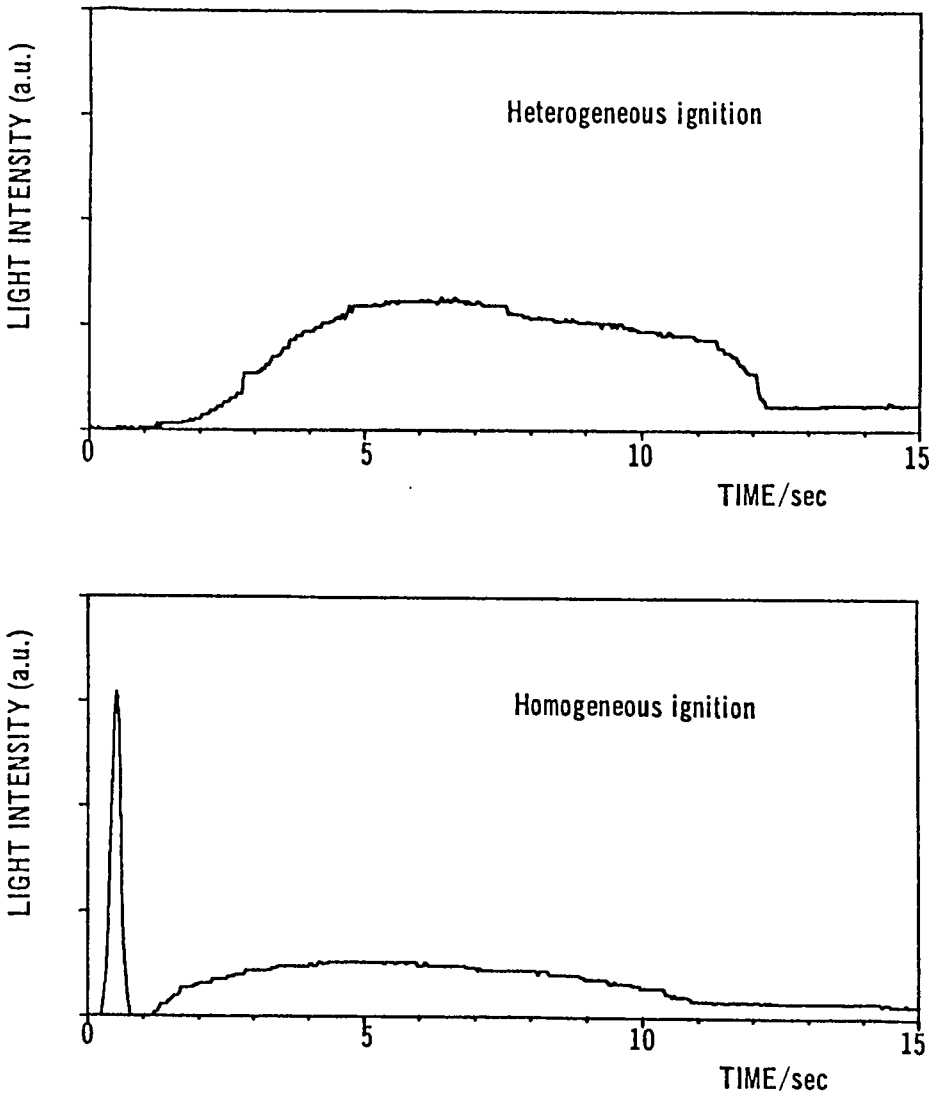

FIGURE 3. TYPICAL RESULTS OF LIGHT EMISSION MEASUREMENTS DURING COMBUSTION OF COAL AND CHAR PARTICLES

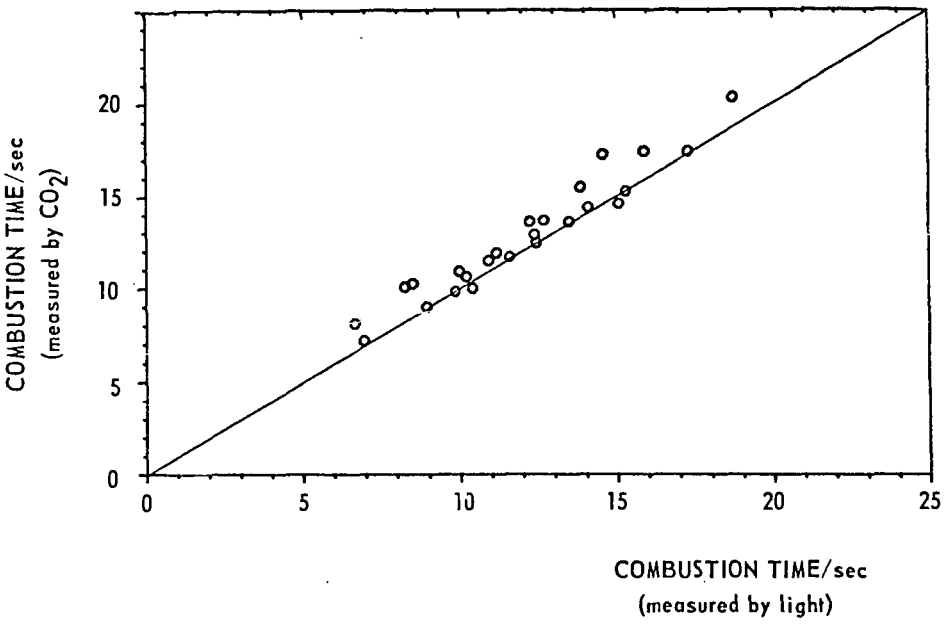

FIGURE 4. COMPARISON BETWEEN THE DIFFERENT TECHNIQUES USED FOR MEASURING COMBUSTION TIMES

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